Developing a Philosophy for Testing of Digital Protective Relaying Schemes

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INTRODUCTION

The increased use of digital relaying systems, with their extensive self-test features, has prompted many utilities to question the testing procedures that they have used for many years on electromechanical and electronic relays. The test programs developed for this new generation of protective relays must be based on knowledge of the relay design, as well as on an understanding of the purpose of the testing.

TEST CATEGORIES

Protective relay tests may be classified by the purpose of the testing. Four categories of testing will be discussed in this paper: Evaluation or Qualification Testing, Acceptance Testing, Commissioning or Installation Testing, and Periodic or Maintenance Testing.

Evaluation or Qualification Testing

Evaluation or Qualification tests are performed on a relay before it is accepted for use by the utility. These tests will typically show that the relay meets all the manufacturer's specifications and appropriate standards. If needed, the Evaluation tests may include Model Power Systems tests to demonstrate that the relay will meet the requirements for a specific application such as single phase tripping, or protection of series compensated lines.

Acceptance Testing

Acceptance tests are typically performed by a utility on all newly purchased relays as they are received. These tests are primarily intended as a Quality Assurance test.

Commissioning or Installation Testing

Commissioning tests are typically performed after the relay is installed, but before it is placed in service. The Commissioning tests are intended to verify that the relay is functioning properly, that the settings for the specific application have been properly applied, and that all inputs and outputs to the relay are wired correctly and operating properly.

Periodic or Routine Maintenance Testing

Periodic or Routine Maintenance tests are typically performed at scheduled time intervals, or when a relaying problem is suspected. These tests are intended to verify that the relay is still functioning properly, and that all external wiring to the relay is intact.

RELAY CONSIDERATIONS

Hardware Reliability

The reliability of various types of protective relays has been discussed in previous papers [1,2]. The electromechanical relays (EM) have the lowest failure rates (highest reliability), followed by the digital relays and the electronic relays. This data, however, is somewhat misleading since the electromechanical relay is a single function while the others are complete systems containing as many as 50 individual functions. On an overall protective scheme basis, the digital relaying systems have the lowest failure rates and the EM the highest.

Firmware Reliability

Firmware reliability was not an issue with electromechanical relays, nor with the first generation of electronic relay systems. Figure 1 shows the relative hardware-firmware design effort as the protective relays have evolved [2]. In a digital relay system the firmware design effort is much greater than the hardware design effort. One reason that the digital relay hardware is more reliable than the electronic relay is the reduction in the amount of hardware. At the same time, however, the increase in the importance of firmware has introduced a new concept -- firmware reliability. The digital relay firmware determines how the relay will perform on the power system; it will determine the overall security and dependability of the protective system. Unfortunately, the reliability of the relay's firmware can not be quantified in the same manner as the reliability of its hardware.

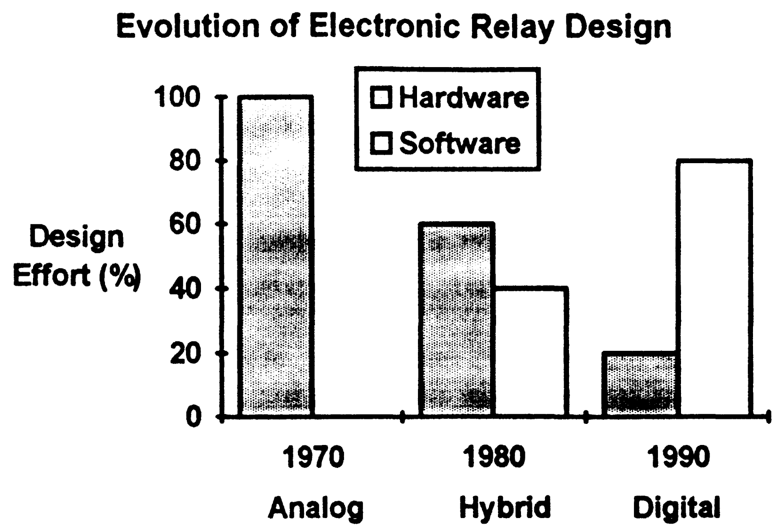

Figure 1

Self Test

In a recent survey of Southeastern US utilities [6], the self checking features of the digital relays tied with cost as the primary reason for using microprocessor transmission line relays. Estimates of the effectiveness of the self checking features range from 75 to 95 %. Regardless of the thoroughness of the self check, however, there will be some problems that may not be discovered. These areas include portions of the relay hardware and firmware and the external wiring to the relay. For example, self check can not determine that the trip outputs are connected to the proper breaker nor can the self test feature detect an error, or "bug", in the design of the relay firmware. The main impact of the self check is in the area of routine or maintenance testing. It is expected that self checking will allow the utility to extend the interval between routine testing of the relays by automatically detecting problems that heretofore were disclosed by the routine testing. One utility [3] has increased their routine maintenance program test interval to ten years; the results of the survey [6], however, indicate that the majority of the utilities responding still intend to test every two years.

TEST EQUIPMENT

The nature of test equipment available to a utility will affect the type and extent of testing performed by the utility. Because the purpose of Evaluation Testing is to assess the operating characteristics of the relay system, it is mandatory that the current and voltage waveforms represent true signals that will occur on a power system. Simplified test equipment that can not reproduce the full range of currents and voltages seen by the relays in service will not yield a reliable evaluation. For this reason, most manufacturers use Model Power Systems in the development and testing of relay systems. In the past, these Model Power Systems were of analog design and tended to be expensive; therefore, only a limited number of utilities had the facilities to perform complete transient testing of protective relay systems. Recently, the advancements in amplifier design, coupled with the lower burdens of the newer relay designs, has resulted in a new generation of lower cost digitally based power system simulators. This enables the utility to perform better evaluation testing of new products.

During Commissioning and Periodic Testing of a microprocessor relay, there is less need for the complete functional testing performed on EM and electronic relay systems since all of the protection algorithms are stored in firmware. For example, it is extremely unlikely that a digital distance relay will experience a problem that affects only Zone 1 on phase A, without it being detected by the built-in self test. Testing and plotting of the individual characteristics are not required for microprocessor relays. Many utilities, however, are now using computerized test equipment [3,6]. This equipment greatly reduces the time and effort required to perform a complete functional test of a relay system. This reduction may allow the utilities to perform traditional Periodic Testing on microprocessor relays with little added cost in terms of added test time.

TESTING PHILOSOPHY

Evaluation Testing

The Evaluation test program for a new relay is not greatly affected by the design of the relay, i.e., EM, electronic or microprocessor. This testing must be very thorough, and should include testing of all relay elements and features under a variety of conditions. The fact that a microprocessor relay includes self checking will not help reduce the test content; however, any oscillography data captured by the relay can be of significant value in analyzing the relay performance. A manufacturer may use the same hardware platform for several different types of microprocessor relays. This may help the utility in their Evaluation tests because hardware related tests, such as temperature tests, may not need to be repeated for every relay type. This same flexibility, however, may present a dilemma to the users. When is a digital relay new? What changes in the relay firmware will require re-evaluation? A manufacturer may issue new firmware for a relay due to problems that have been discovered in service, or to upgrade and expand the features of a given relay. The utility must then decide how much re-testing is required to re-qualify the relay.

A paper presented at the recent IEEE winter Power Meeting [7] describes one utility's extensive evaluation program for series compensated line protection. This evaluation program extended over a period of 18 months, involved 8 relay systems, and 115,000 test cases. In the conclusion the authors stated "...if the scope of the study and the number of tests performed had been reduced, many or even most of the problems encountered might well have been missed." Few utilities will be able to dedicate the necessary resources for a project of this scope, but it does point out the importance of the evaluation test program. Concerning microprocessor based relay firmware changes, the authors state "...comprehensive testing will be needed before a relay software version is changed in the field." In some instances, the user may not be aware that a firmware revision has occurred until the relay is received [3].

The performance of a relay system should be measured primarily in terms of security and dependability. The desired balance between security and dependability will vary among utilities. To evaluate a relay system's security requires subjecting the relay under evaluation to system disturbances for which it should not trip. Examples of these disturbances are: external faults, fault current reversals, line and/or transformer energization, changes in load, power swings, loss of relay potential, communications channel failures, current transformer saturation, etc. The dependability of the relay system will be affected by fault resistance, load flow, source to line impedance ratio, capacitive coupled voltage transformers, communications channel errors, etc. Other possible performance criteria include maximum fault clearing time, sensitivity, phase selection, fault location accuracy, etc.

Acceptance Testing

Acceptance tests are not done by all utilities. The tests that are performed may range from a simple physical inspection of the hardware, to a complete electrical test. In some cases this step may be skipped and the Commissioning Test will also serve as the Acceptance Test. Each utility will probably determine the need for Acceptance Testing based on the history of the product and manufacturer. With digital relays, the content of the Acceptance Test can be reduced. There is no need to verify the operation of every element in a digital relay at the time of Acceptance Test, as it is stored in firmware. A typical Acceptance Test for a digital relay might consist of applying DC voltage to verify the relay model and firmware version, and AC quantities to verify the magnetics and Analog to digital converters.

Commissioning Testing

All utilities will perform some testing at the time that the relay is installed. The complexity of the testing will vary based on the utilities' procedures. A recent survey [6], indicated that over 75% of the utilities responding perform a complete check of all relay functions at the time the microprocessor relay is installed. It can be argued that, since the actual protection functions of a microprocessor relay reside in the firmware, the Commissioning Tests can be reduced in scope. Once the digital relay firmware has been verified in the Evaluation Testing, the performance of the firmware should be the same for new relays. Extensive testing of the firmware is not required during the Commissioning Tests. If, however, the firmware has been revised by the manufacturer, additional testing may need to be performed at this time to ensure that the relay still functions as before. At least one utility has reported new "bugs" with updated firmware [3].

Because the Commissioning Tests are intended to check more than the relay system itself, the procedures will typically include tests to verify external wiring to the relay system such as current and potential, trip circuits, reclosing controls, communications channels, etc. Typically, all of the relay system inputs and outputs will be verified at this time.

Periodic Testing

Periodic or Routine Maintenance Testing has been used historically to detect component failures in relays that, if not corrected, might adversely affect the relay performance, and to detect component value changes that might affect the settings applied to the relay. Therefore, Periodic Testing may be most directly affected by the self check features included in the new microprocessor relays. The self check feature will report many relay problems that could not previously have been detected without performing routine maintenance. The self check, however, can not perform a complete test of the relay, especially the input and output circuits. Since most microprocessor relays include some metering data, this information can be used to supplement the built-in self check features. By periodically comparing the values of current and voltage reported by the digital relay with another digital relay on the line, or with existing panel meters, the operation of the analog circuits in the digital relay can be verified. Additional testing must be performed to check the operation of contact inputs and outputs, including the interaction of the relay with other protection and control devices in the substation.

A typical digital line protection relay package includes the ability to capture oscillography data during disturbances on the power system. The oscillography data includes digitized currents and voltages seen by the relay, the status of external contacts connected to the relay, the status of various measuring units and logic points internal to the relay and the relay settings. Analysis of this data following a power system disturbance will show the performance of the relay, its associated channel, and power system components such as the circuit breaker. Even on correct operations, the data may reveal that the channel timing was not as expected, or possibly that one of the breaker poles was slow to open. In the case of a suspected misoperation of a digital relay, the oscillography data can be used both by the utility and by the relay manufacturer to ascertain the cause of the problem.

Since most utilities will elect to perform some testing on a digital relay after installing revised firmware, the Periodic Test interval may well be determined by how often the user installs new firmware rather than by the maintenance schedule. If the firmware change is due to added features, the user may decide to delay the installation, or perhaps decide not to upgrade at all. If, on the other hand, the change is due to a defect in the firmware, the user may be forced to install the revised firmware, or to accept the possibility of misoperation. In some instances, the utility may decide that a firmware revision requires that a relay with the revised firmware undergo Evaluation Testing before the modified firmware is placed in service.

SUMMARY

The increasing installed base of microprocessor relays will lead the utilities to develop new philosophies for testing protective relays. It is only during the Evaluation Testing that the complete relaying system is fully tested. The Evaluation Tests must be designed to fully explore the firmware of the relay, including both the measuring elements and the logic. Theoretically, the

Routine Maintenance test intervals can be increased for the microprocessor relays, due primarily to the self check features augmented by the analysis of oscillography data captured by the relay. In fact, however, proliferation of firmware upgrades and revisions may actually cause the test interval to be reduced! Many of the decisions created by new firmware versions will be influenced by the user's perceptions of the manufacturer's firmware quality control and test. If the user has experienced problems after installing a new version of firmware, he will be more likely to perform re-qualification testing in addition to periodic testing.

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